RESEARCH TRIANGLE INSTITUTE

Third Quarterly Technical Report

INVESTIGATION OF LOW TEMPERATURE MULTILEVEL DIELECTRICS FOR APPLICATION FOR RADIATION TOLERANT, SUBMICRON-SCALED IC TECHNOLOGY

Period Covered: 1 July 1989 to 30 September 1989

RTI Project No. 415U-3627

STRATEGIC DEFENSE INITIATIVE ORGANIZATION
Innovative Science and Technology Office

Office of Naval Research
ONR Contract No. N-00014-86-C-0421

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Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS NONE
2a. SECURITY CLASSIFICATION AUTHORITY ---	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release unlimited distribution
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE ---	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) 83B-3627	5. MONITORING ORGANIZATION REPORT NUMBER(S) Office of Naval Research
6a. NAME OF PERFORMING ORGANIZATION Research Triangle Institute 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION Office of Naval Research
6c. ADDRESS (City, State, and ZIP Code) P.O. Box 12194 Research Triangle Park, NC 27709	7b. ADDRESS (City, State, and ZIP Code) 800 N. Quincy St. Arlington, VA 22217-5000
8a. NAME OF FUNDING/SPONSORING ORGANIZATION SDIO/IST 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER N-00014-86-C-0421
8c. ADDRESS (City, State, and ZIP Code) SDIO/T/IS Pentagon Washington, DC 20301-7100	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Investigation of Low-Temperature, Multilevel Dielectrics for Application for Radiation Tolerant, Submicron-Scaled IC Technology (Unclassified)

12. PERSONAL AUTHOR(S) R.J. Markunas et al.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Quarterly	FROM 7/1/89 TO 9/30/89	10/15/89	

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Silicon Dioxide, Oxynitrides, Plasma CVD

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The following report details the progress on ONR contract number N-00014-86-C-0421 during the period from July 1, 1989 to September 30,1989. This program entails a joint effort between Research Triangle Institute and North Carolina State University.

The Gen 2 remote plasma reactor system is on line at RTI. Work has begun in this system on the deposition of oxide, nitride, and oxide nitride oxide MOS structures. Enhancement mode n-channel MOSFETs have been fabricated using an all-low temperature process (<600°C).

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION
22a. NAME OF RESPONSIBLE INDIVIDUAL R.J. Markunas	22b. TELEPHONE (Include Area Code) 919-541-6153 / 22c. OFFICE SYMBOL

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

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1.0 INTRODUCTION

The following report details the progress on ONR Contract Number N-00014-86-C-0121 during the period from 1 July 1989 to 30 September 1989. This program entails a joint effort between Research Triangle Institute and North Carolina State University. Funding is being provided by the Innovative Science and Technology Office of the Strategic Defense Initiative.

The Gen 2 remote-plasma reactor system is on line at RTI. Work has begun in this system on the deposition of oxide, nitride, and oxide nitride oxide MOS structures. These structures show improved charge to breakdown characteristics over previously reported structures grown in the original RTI remote-plasma reactor. Enhancement mode n-channel MOSFETs have been fabricated using an all-low temperature process ($< 600^\circ$ C). These results are described in Section 3.

2.0 NEW ULTRA-HIGH PURITY REMOTE PLASMA DEPOSITION SYSTEM

A new ultra-high purity (UHP) deposition system is now on line and operating at RTI. This reactor takes advantage of the insights we have gained into the oxide and nitride deposition processes. The reactor has an all quartz deposition region for high purity, and a long flow tube type design to minimize eddie current flows. The all-quartz construction of the reaction zone allows us to use external heaters to heat the sample, which greatly simplifies the internal construction of the reactor and eliminates many sources of contamination. The reaction zone is heated with infra-red lamps. This radiation should couple very well into any water-related byproducts and help to drive them off of the reactor walls so they can be transported out of the reaction zone. The gas delivery lines are very short to minimize contamination from the lines, and each gas will be filtered at its injection point with a .05 micron filter. All metal sealed leak valves are used for flow control so that the gas lines are entirely UHV compatible and bakeable. The system provides much latitude for adjustment of sample position and plasma region position. We believe this system will allow us to make major strides in the development of high-quality, highly reliable dielectrics.

Already the new system is proving its viability in the area of nitride deposition. The charge to breakdown data shown in Figure 1 is from a nitride deposited at 300 °C in the new system. This nitride film passed a total charge of over 400 C/cm^2 before breaking down. The total voltage shift was less than 0.1 Volt.

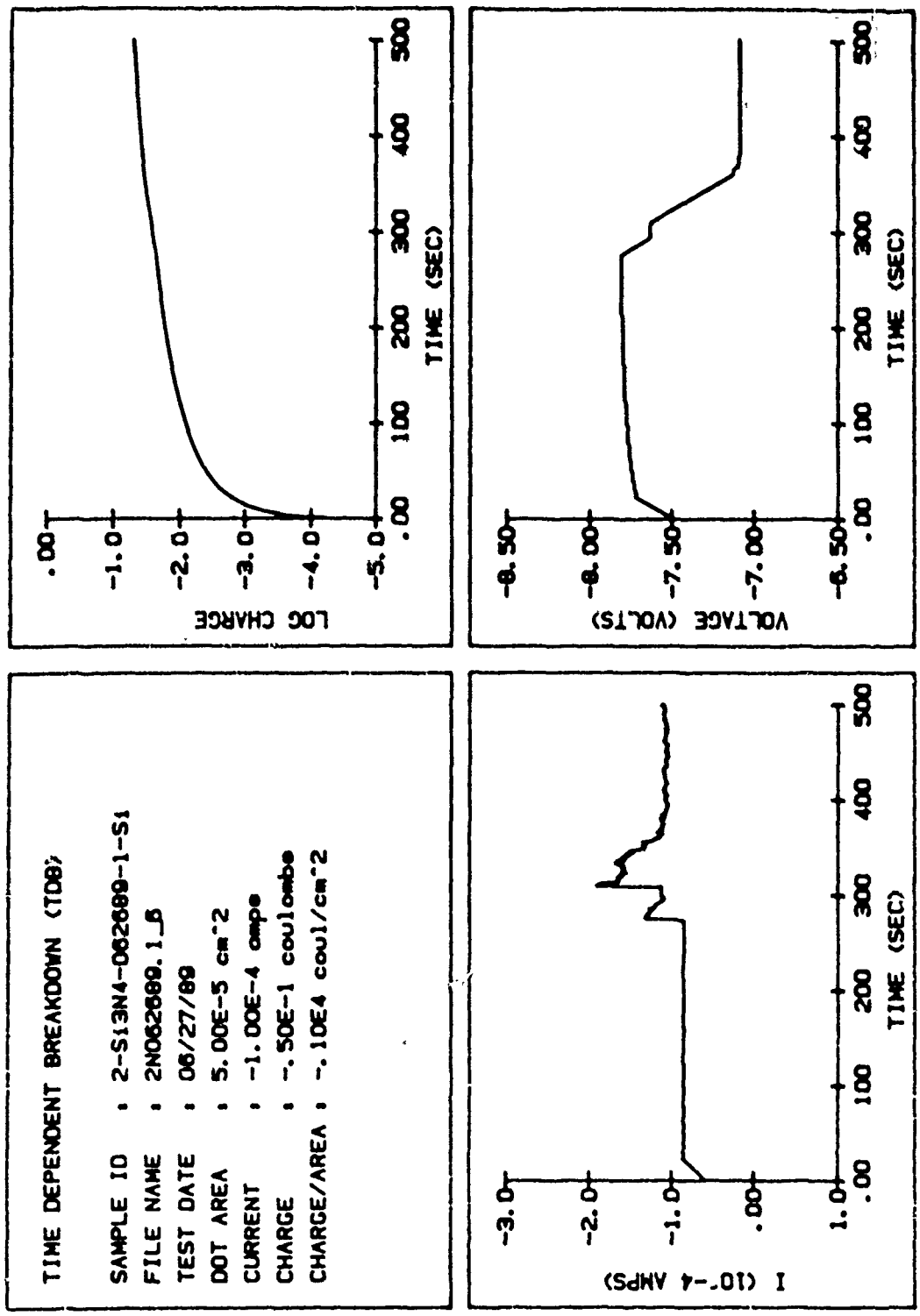

FIGURE 1: Time dependent breakdown measurement for Si_3N_4 film ($\sim$ 10 nm thick) deposited at 300 °C using the new ultra-high purity reactor.

The best nitride films out of the original reactor had total charge to breakdown values of 1 C/cm^2. This exciting new result we attribute to the overall improved purity in the new reactor.

2.1 UHP Oxide Deposition

Deposition studies of SiO_2 have been initiated in the UHP system at RTI. So far deposition runs have been carried out at 300°C. Various conditions have been used as shown in Table 1.

Figure 2 shows CV data from an MOS capacitor fabricated on wafer 2-062389-1. This particular run incorporated nitrogen as a process gas in an attempt to deposit and oxynitride film. Auger analysis indicated no detectable nitrogen. However, the interface state density measured on this sample is very low, $1 \times 10^{10} cm^{-2} eV^{-1}$. This oxide is on the order of 8.5 nm thick. Charge to breakdown measurements on this material indicate a charge tolerance level of 0.2 Ccm^{-2} before breakdown. The change in voltage to maintain the current throughout the measurement was only 30 mV. This result represents a 100 fold improvement in the charge to breakdown characteristics of the oxide films. These capacitors have *Aluminum Electrodes.* This charge to breakdown tolerance is good for SiO_2 MOS structures with Al electrodes.

Data from other oxide deposition runs with other parameters are shown in Figures 3 and 4. At this point the films are consistently yielding charge to breakdown values of 0.2 Ccm^{-2}.

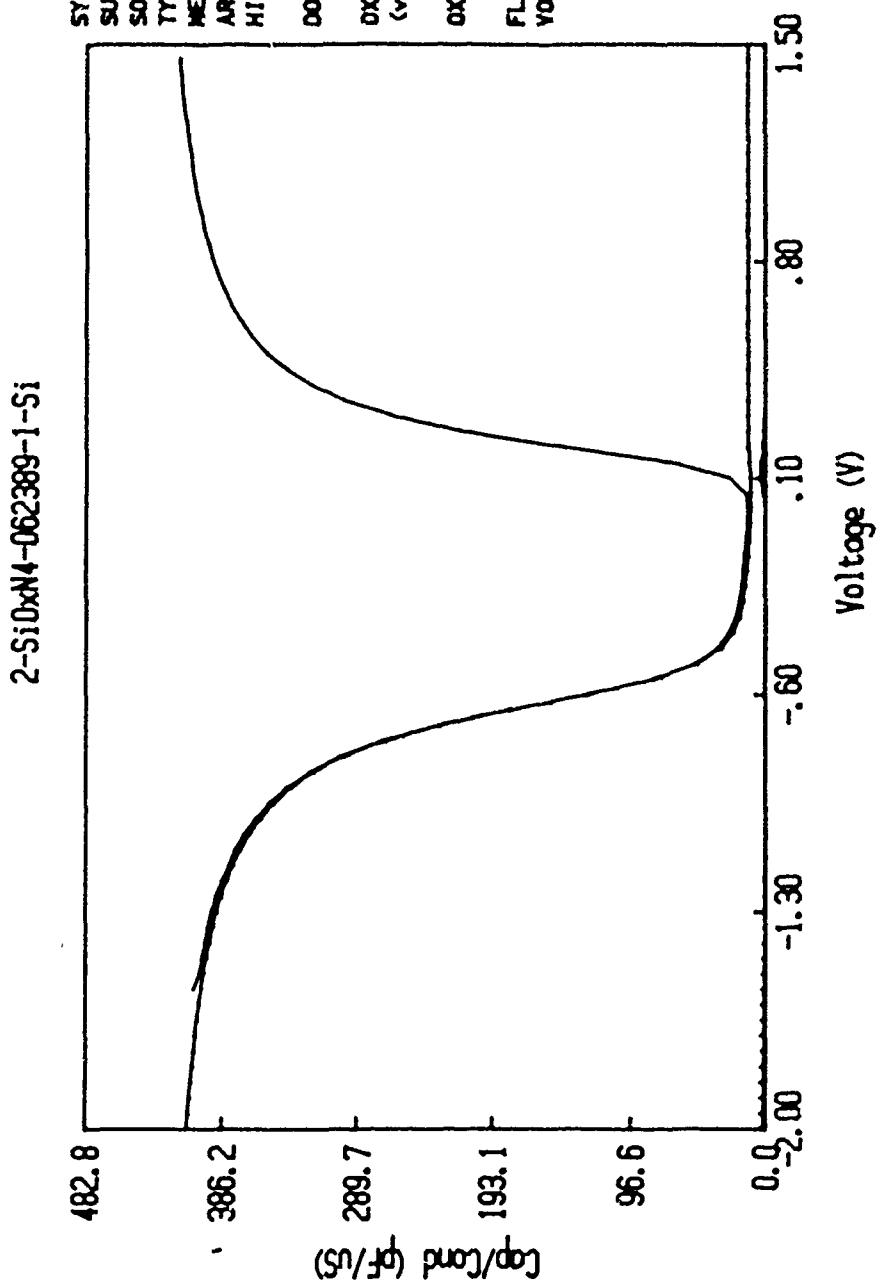

FIGURE 2: C-V characteristics of an oxide structure deposited in the UHP deposition reactor at 300 °C.

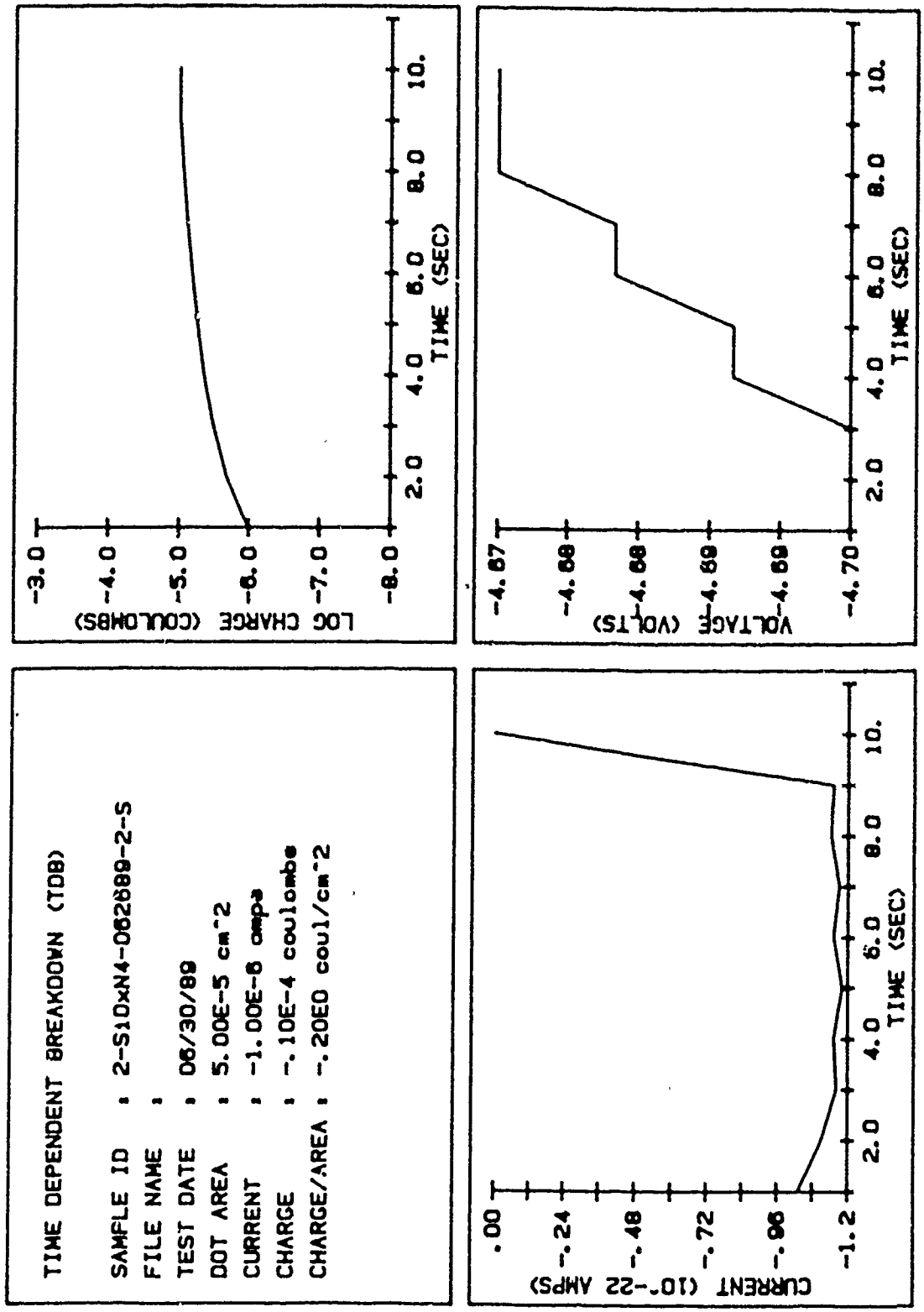

FIGURE 3: Charge to breakdown measurement on an oxide structure deposited in the UHP deposition reactor.

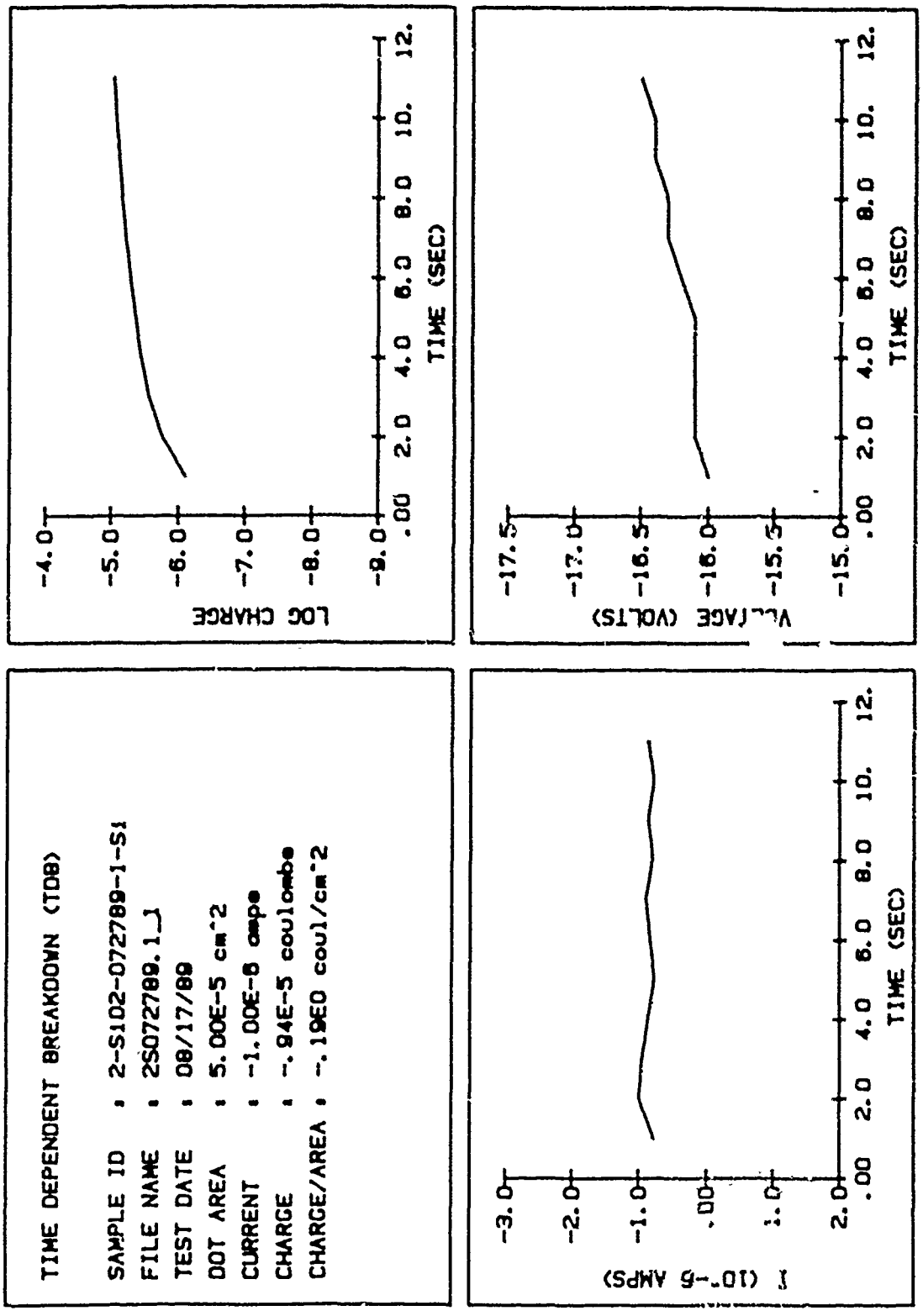

FIGURE 4: Charge to breakdown measurement on an oxide structure deposited in the UHP deposition reactor.

2.2 UHP Nitride Deposition

Deposition studies of Si_3N_4 have been initiated in the UHP system at RTI. So far deposition runs have been carried out at 300°C. Various conditions have been used as shown in Table 1.

We have found that the deposition temperature of the nitride is very important to its electrical performance. This same feature was noted in the nitride deposition studies carried out in the original RTI reactor. In the original RTI reactor, 400°C was the temperature which yielded the best films from the electrical standpoint. In the UHP system, nitride films have been deposited at 300°C which surpass the performance of the original system nitrides.

Charge to breakdown measurements for other nitride samples are shown in Figures 5 and 6.

2.3 UHP Oxide-Nitride-Oxide Insulator

An oxide-nitride-oxide composite insulator structure has been deposited in the UHP reactor. This structure consists of approximately 3.5 nm of oxide, followed by 15 nm of nitride, finally followed by 2.5 nm of oxide. C-V characteristics shown in figure 22 indicate that this structure has a midgap interface state density of about $10^{11}cm^{-2}eV^{-1}$. There is no hysteresis in the high frequency data. The equivalent oxide thickness is 13.5 nm. This structure supports a voltage of 19.5 V at a current of 1 microamp. For an oxide structure of equivalent capacitance this would represent a field of 14.2 $MVcm^{-1}$. This structure can support a current of a

TABLE 1: Deposition Rate Under Which Oxides Were Deposited and Corresponding Electrical Characteristics

SAMPLE NO.	DEPOSITION RATE nm/min	MIDGAP D_{it} ($cm^{-2}\,ev^{-1}$)	CHARGE TO BREAKDOWN ($C\,cm^{-2}$)
111888-2	1.12	2.9×10^{10}	1.2×10^{-3}
112188-1	0.16	4.3×10^{10}	1×10^{-2}
112188-2	0.18	4.5×10^{10}	Could Not Measure
112288-2	1.24	2.2×10^{10}	3×10^{-2}

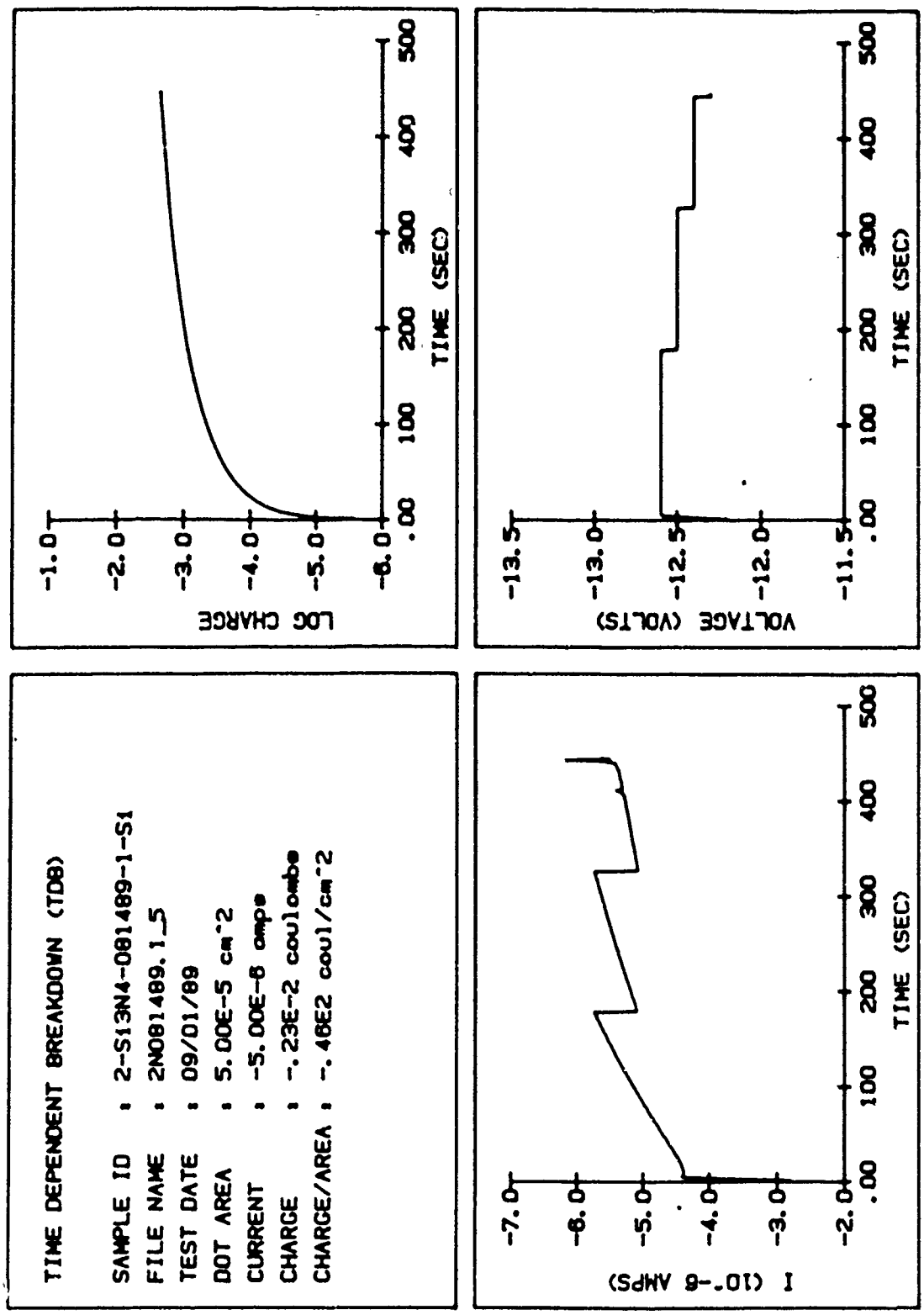

FIGURE 5: Charge to breakdown measurement for nitride structures deposited at 300 °C in the UHP deposition reactor.

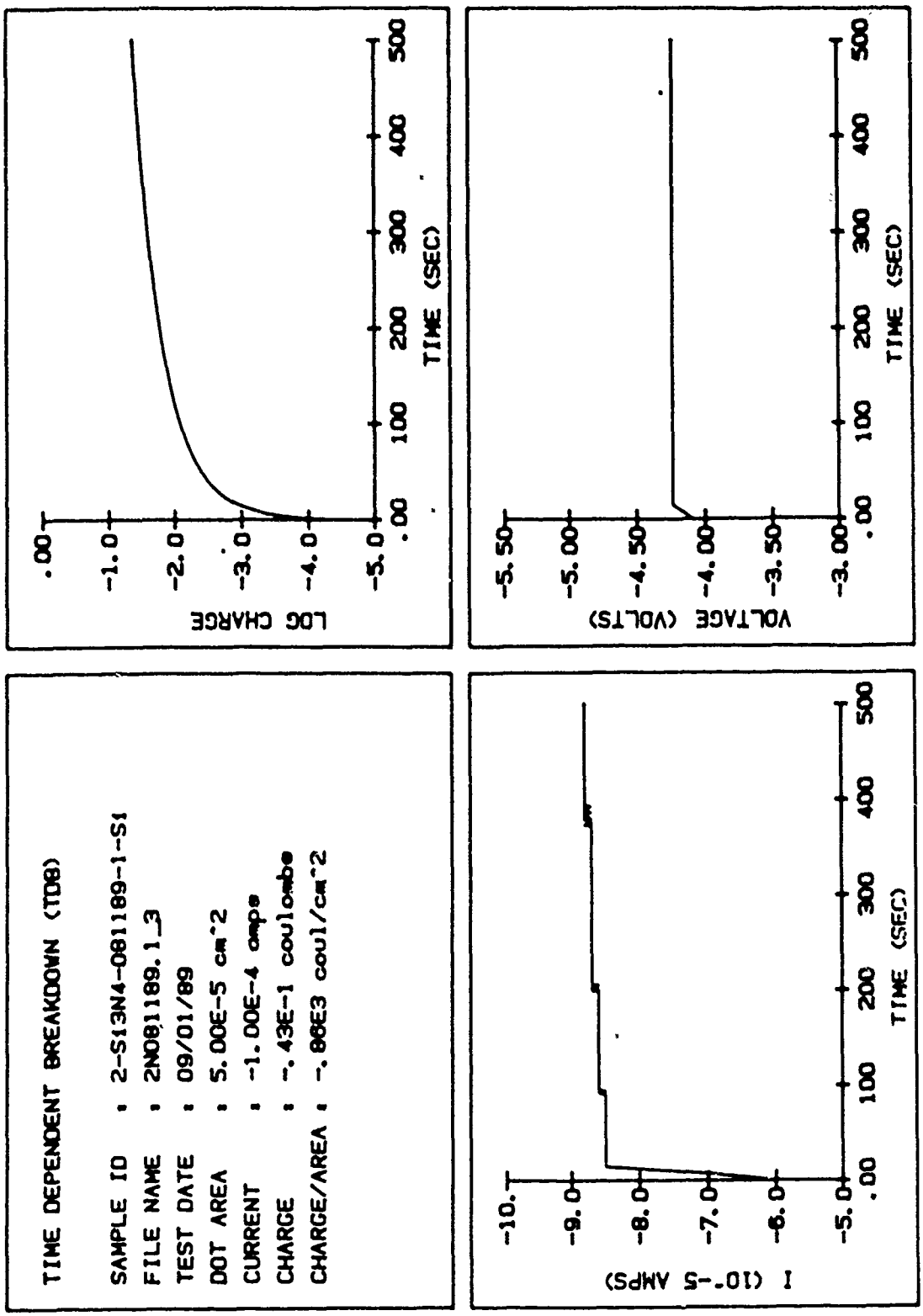

FIGURE 6: Charge to breakdown measurement for nitride structures deposited at 300 °C in the UHP deposition reactor.

micro-amp at an oxide-equivalent field of 14.2 MV/cm. The charge to breakdown for this structure is on the order of 0.6 Ccm $^{-2}$, (see Figure 7).

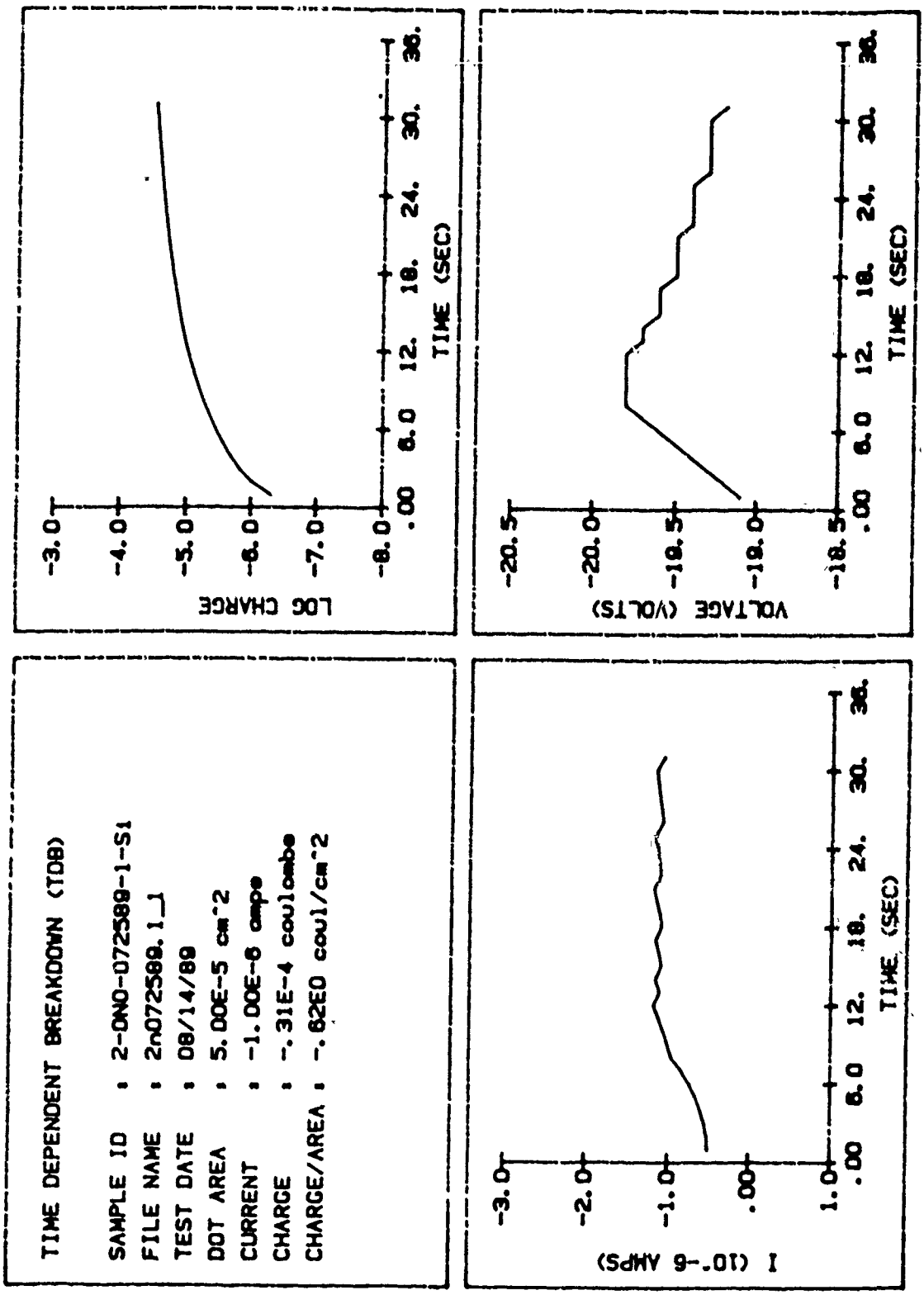

FIGURE 7: C-V characteristics of O-N-O structures deposited sequentially in the UHP deposition reactor.

3.0 FET FABRICATION

Inversion mode n channel Si MOSFETS have been fabricated using the RPECVD oxide. The maximum processing temperature was a 600/(deC anneal of the implanted source drain regions. The IV characteristics are shown in Figure 8. At a gate length of 2 microns the transconductance of the transistors was about 80 mS/mm. The gain is limited principally by the source drain contact resistance. Capacitors were also fabricated on chip with the FETs. This gives some idea of the effect of the combined processing steps on the quality of the oxide-Si interface. The CV characteristics are shown in Figure 9. The interface state density for the structure is in the mid $10^{10}cm^{-2}eV^{-1}$ range.

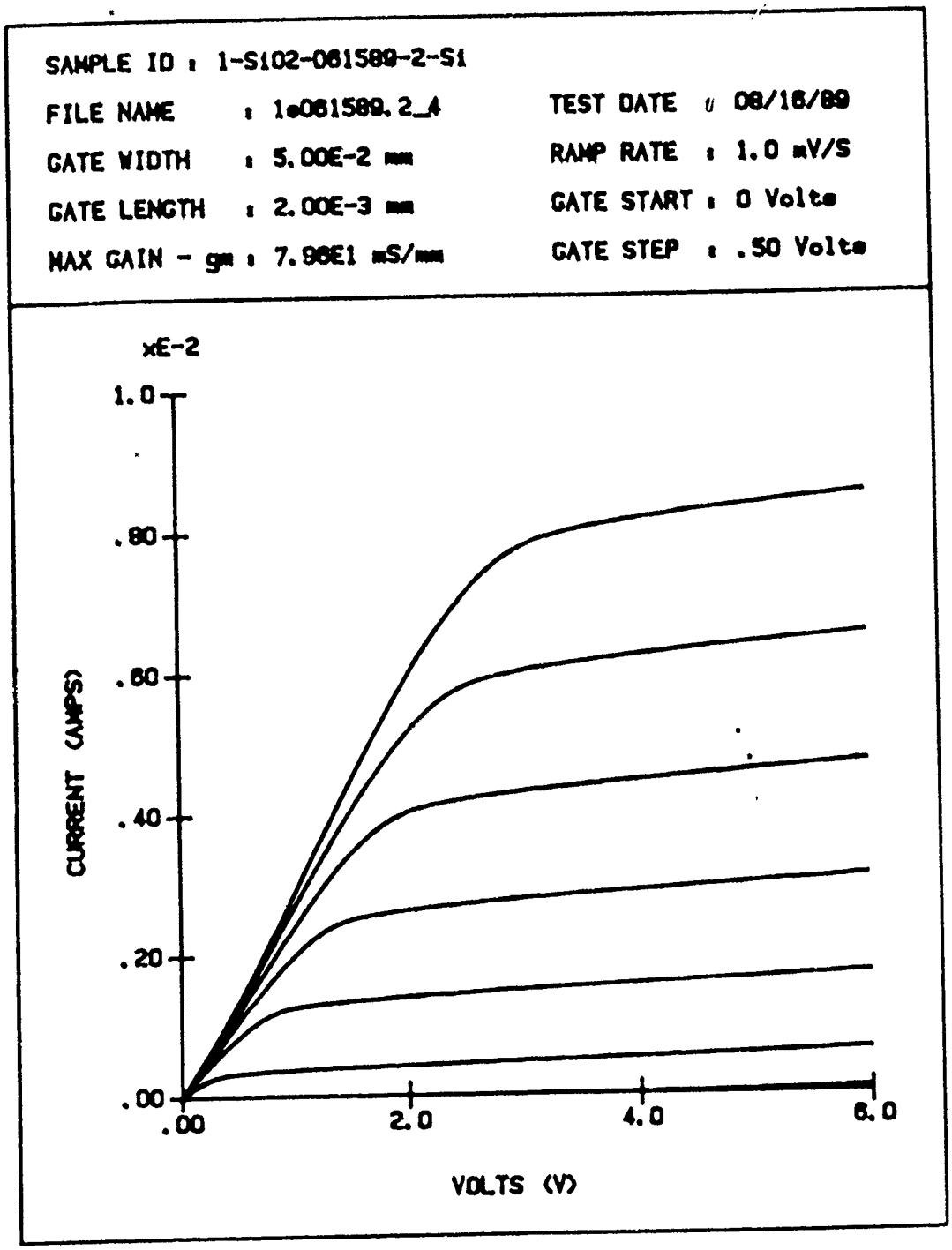

FIGURE 8: Transistor characteristics of transistor with deposited gate oxide. Maximum processing temperature is 600 °C.

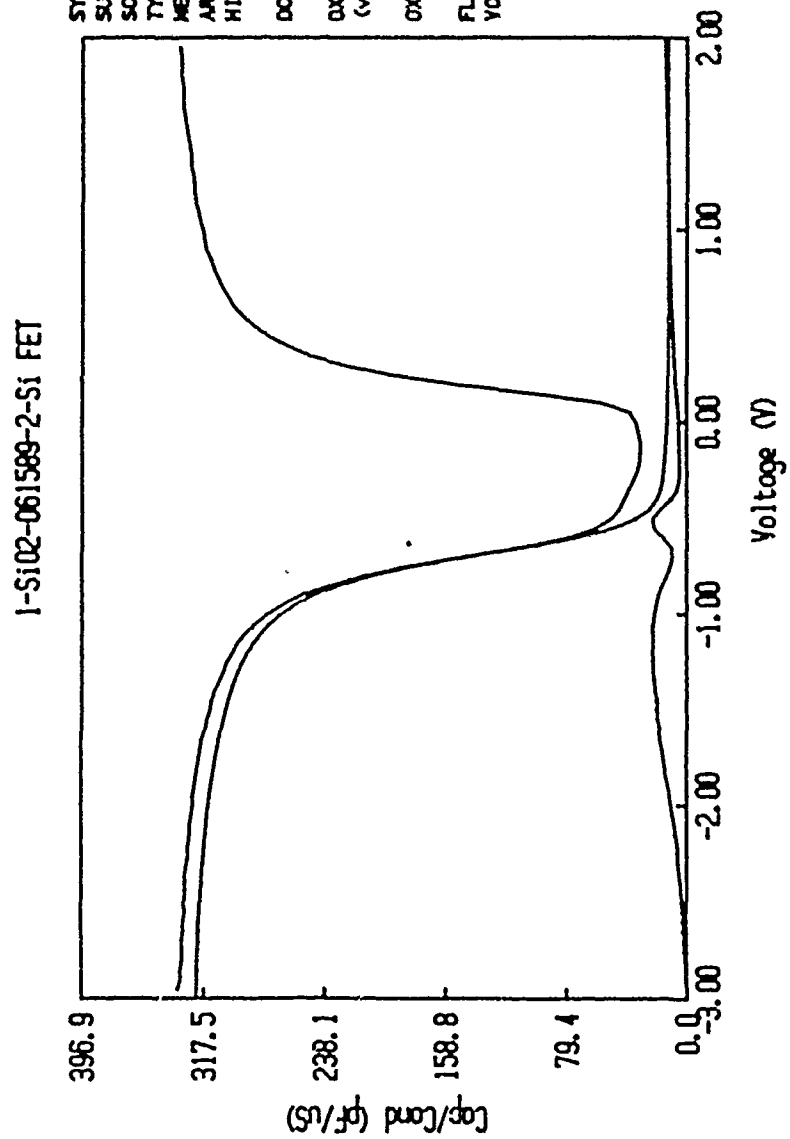

FIGURE 9: C-V characteristics from capacitors on chip with transistors fabricated using oxide deposited at 300 °C.

4.0 SUMMARY

The new ultra-high purity deposition system has been brought on line and is being exercised. This system has already shown the capability of improving the quality of the depositied oxide and nitride films. The charge to breakdown tolerance of the oxide films has improved by an order of magnitude, and the tolerance of the nitride films has improved by 2 orders of magnitude over films deposited in the original RTI reactor.

Inversion mode n-channel MOSFETs have been fabricated with an all low temperature process ($< 600^\circ C$), which have transconductances of 80 mS/mm.